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Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes

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Abstract

This study deals with eating quality of pre-peeled potatoes. The effect of raw material quality (cultivar, duration of wound healing and storage) on chemical composition of raw potatoes, and sensory quality and aroma composition of cooked pre-peeled potatoes were determined. Potatoes were knife peeled, vacuum-packed, stored at 4 °C, and evaluated after 6 days of shelf-life. Significant differences in chemical composition, sensory quality and aroma composition were found among the 6 cultivars. Storage (0, $1\frac{1}{2}$ and 6 months) also affected the sensory quality and the aroma composition. For surface hardening an effect of wound healing time (2 or 4 weeks at 14 °C) was observed, since 4 weeks resulted in lower intensity in surface hardening. During long-term storage the intensity in surface hardening decreased. The aroma compounds linalool, methional, nonanal and decanal were correlated to potato flavour and rancidness, whereas off-flavour/off-taste seemed to be correlated to nonvolatile components. Enzymatic browning of potatoes was positively correlated with PPO activity, tyrosin and chlorogenic acid a well as aspartic and glutamic acid, but negatively correlated to caffeic acid. The study showed that the quality of pre-peeled potatoes is very sensitive to raw material quality, and the time of year being processed.
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1. Introduction

In the last decades consumers' demand for convenient, ready-to-use or ready-to eat food products with a safe and fresh-like quality has increased (Day & Gorris, 1993). Minimally processing techniques, shelf-life and quality aspects of such products are subjects of high relevance for future product development (Ohlsson, 1994; Ahvenainen, 1996).

Raw pre-peeled potatoes form the basis for minimally processed ready-to-cook potatoes. The product is an alternative to pre-cooked vacuum-packed or canned potatoes. Pre-peeled potatoes are peeled, packed in vacuum or modified atmosphere and have a limited shelf-life of 5–7 days at 4–5 °C, due to microbiological, sensory and nutritional deteriorations (Keijbets, 1988; Chassery & Gormley, 1994; Schlimme & Rooney, 1994). The major quality aspect in pre-peeled potatoes is the microbial quality, which, due to safety, has been investigated extensively with respect to effects of chemical preservation agents and modified atmosphere packaging (Keijbets, 1981; O'Beirne & Ballantyne, 1987; Giannuzzi & Zaritzky, 1991, 1993; Chassery & Gormley, 1994; Giannuzzi, Lombardi, & Zaritzky, 1995). Some of the investigations showed that ascorbic- and citric acid and modified atmosphere packaging could replace the use of sulphur dioxide. Chemical preservation and modified atmosphere packaging were shown to decrease the surface browning of the potatoes and to improve the

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appearance of the product (O'Beirne & Ballantyne, 1987; Sapers & Miller, 1995). With respect to shelf-life, no attention was addressed to sensory quality of pre-peeled potatoes in terms of aroma and taste quality. Texture is a major quality aspect in pre-peeled potatoes as most pre-peeled potatoes form a compact superficial surface layer (Svensson, 1971; Sapers, Cooke, Heidel, Martin, & Miller, 1997). This surface hardening, or so-called case hardening, of pre-peeled potatoes gives an elastic, hard and crisp surface with varying thickness, which is experienced as a hard and lumpy structure during chewing of the potato and limits the utilization of pre-peeled potatoes. Surface hardening is demonstrated to increase by addition of chemical preservation agents such as ascorbic and citric acid, and sodium acid pyrophosphate (Svensson, 1971; Sapers & Miller, 1995). The surface hardening is also observed to increase by an increased exposure to mechanical stress of the potatoes during handling and peeling in the process line in the industry (Lulai, Glynn, & Orr, 1996; Kaack, Larsen, & Thybo, 2002a). As the surface hardening of pre-peeled potatoes increases during a shelf-life of 5–7 days, it is speculated to be a wound healing process with deposit of suberin in cell layers below the wounded surface (Thomson, Evert, & Kelman, 1995; Kaack, Larsen, & Thybo, 2002b). The suberization will cross-link the cells resulting in strong brick-like tissue structures. However, very little evidence of the reason for surface hardening in raw pre-peeled potatoes is addressed. Furthermore, no attention has been addressed to sensory quality of pre-peeled potatoes in terms of aroma and taste quality.

New approaches in improving the quality and the shelf-life of minimally processed vegetables are important subjects for increasing the sale of raw pre-peeled potatoes in the catering and retail market. This includes optimization of raw material quality, processing conditions (gentle handling, strict hygienic practices, correct packaging technology), distribution and retailing (Ohlsson, 1994; Ahvenainen, 1996).

In order to obtain a better quality of pre-peeled potatoes, this study addresses the effects of agronomic factors as cultivars, wound healing time and long-term storage on sensory quality of pre-peeled potatoes. Furthermore, this study will deal with the chemical variation of the raw potatoes to understand the reason for the sensory quality differences in discolouration, aroma and taste of cooked pre-peeled potatoes.

2. Material and methods

2.1. Cultivation and storage of potatoes

The potato cultivars Berber, Arkula, Marabel, Sava, Folva and Agria were grown in three replicates on a fine sandy soil at Tylstrup Research Station in 1999. The cultivars used represent different maturity classes and are above arranged in order of increasing lateness of maturity. Potatoes were fertilized with 140 kg N, 180 kg K and 11 kg P per ha, planted on April 27, irrigated and managed according to commercial praxis. Date of chemical wine desiccation were adapted to variations in cultivar maturity, and were performed when tuber samples started to show small white spots on the surface in water boiling tests. All cultivars were harvested on August 25. Tubers were size graded and the 40–55 mm fractions were divided in two subsamples and used for further experiments and analysis. One subsample was wound healed at 14 °C for 2 weeks and the other sample was wound healed at 14 °C for 4 weeks to allow skin setting. After wound healing, potatoes were stored at 4 °C and 95% relative humidity without use of chemical sprout inhibitors. Samples were analysed right after the wound healing (0 month) and after $1\frac{1}{2}$ and 6 months of storage. The abbreviations of the samples are given by the as e.g. Be1.5[2]: Be = Berber, 1.5 = storage (0, 1.5 or 6 months), [2] = wound healing ([2] or [4] weeks).

2.2. Chemical analysis of raw potatoes

From each experimental unit a 2 kg blemish-free tuber sample was washed, sliced into cubes, immediately frozen to −30 °C in a blast freezer and subsequently freeze-dried in a Gamma 1–20 freeze dryer (Christ Freeze Dryers, Osterode, Germany). Samples were weighed before and after freeze-drying for tuber dry matter determinations.

All chemical analyses were performed on freeze-dried samples.

Total-N (DUMAS), nitrate, potassium and starch were analysed according to standard methods (Anon, 1971; Best, 1976; Åman & Hesselman, 1984; Hansen, 1989). Free amino acids asparagine, aspartic acid, glutamine and glutamic acid were analysed by HPLC as described by Hansen-Møller (2000). The specific activity of polyphenol oxidase (PPO) (μmol O$_2$ mg protein^{-1} min^{-1}) was measured by an oxygen electrode (Hansatech Instruments, King's Lynn, UK) according to Lærke, Christiansen, and Veierskov (2002). The PPO substrates chlorogenic, caffeic acid and free tyrosin were analysed by HPLC (Lærke et al., 2002).

For determination of the enzymatic discolouration potential of tubers, tuber samples were washed and equilibrated at 21 °C for 17 h before analysis. 2 kg tubers/sample were homogenized for 2.0 min at maximum speed in a R602VV blender (Robot-Coupe, Vincennes Cedex, France). Samples of the potato pulp were poured into five Petri dishes and two pieces of filter paper were placed on top of the pulp to avoid foam interfere with oxidation of the tuber juice. Petri dishes

were left at 21 °C without lid and the colour (L∗a∗b∗ colour space) of the soaked filter paper was measured by a CR-310 Chromameter (Minolta, Tokyo, Japan) at various time intervals after initiation of blending. The discolouration potential is expressed as delta-L, delta-a and delta-b, i.e. the mean changes in colour values from 7.5 min until 30.0 min after initiation of blending.

Black spot bruise susceptibility of tuber samples was determined by use of a MIDAS 95 impact pendulum (Argus Electronics, Rostock, Germany) and expressed in Blackspot Index values (0–100) as described by Lærke et al. (2002).

2.3. Processing of pre-peeled potatoes

For each storage, 2 kg of potatoes were peeled for 3 min in a laboratory knife peeler (IMC, type M5, Croxley Green Hearts, UK). Afterwards, a hand peeler was used to remove any residual skin. The potatoes were dried with a towel and 1 kg of potatoes were vacuum-packed in a plastic bag (7 layer co-extrudat polymer of 80 μm; Krehalon Synclair, P-FWP-MAP 12, AC Almere, The Netherlands) with a transmission rate of 5.7 $cm^3 m^{-2} 24 h^{-1}$ for O_2 and 13.9 $cm^3 m^{-2} 24 h^{-1}$ for CO_2 at 23 °C and 0% RH. 2 × 1 kg were peeled and packed for sensory analysis and 2 × 1 kg for aroma analysis. The pre-peeled potatoes were stored at 4 °C for 5 days until sensory and aroma analysis. At the last storage (6 months) Sava and Berber were exposed to 10 min of extra mechanical stress in a potato damage barrel (Scottish Agricultural Centre, Edinburgh, Scotland) after peeling.

2.4. Sensory analysis of cooked pre-peeled potatoes

Each cultivar was boiled in water for 20–25 min in order to optimize cooking time for each cultivar. After 0, 1½ and 6 months of storage whole potatoes of each sample (6 cultivars × 3 field replicates × 2 wound healing times) were analysed by the sensory panel in two repetitions in a totally randomized design with six samples per sensory session. The samples were evaluated while hot (80–85 °C), and one tuber per sample was served for each assessor. A panel of 10 trained assessors evaluated the appearance (yellowness and reflection from surface), texture (surface hardness, firmness, mealiness, adhesiveness and moistness) and flavour and taste attributes (potato flavour, off-flavour and rancidness) by quantitative descriptive analysis (Thybo & Martens, 1998). The attributes were evaluated on a 1–15 point unstructured line scale with the anchor point 'none' on the left side and 'very strong' on the right side. The attribute surface hardening was defined as the degree of presence of a crisp, hard raw-like skin. A 'very high' surface hardening represented a skin of about 5 mm. Off-flavour was determined as the mean taste/

flavour perception of a negative flavour, which occurs in pre-peeled potatoes. The mean of the assessors' scores was calculated and used for statistical analysis.

2.5. Analysis of aroma volatiles in cooked pre-peeled potatoes

All samples were analysed in duplicate. The potatoes were boiled in a steam oven for 45–55 min, dependent on the cultivar. For each analysis, five potatoes were roughly mashed and 125 g was homogenized in 375 g of water. 1 ml of internal standard (4-methyl-1-pentanol (Aldrich, 97%), 50 μl/kg) and 1 ml of Antifoam B, 10% (Sigma) was added to the suspension. The aroma compounds were isolated by a dynamic headspace method where the samples were purged with nitrogen at 200 ml/min for 60 min, and a stainless steel trap containing 100 mg Tenax was used. The traps were thermally desorbed using a TD-4 Short Path Thermal Desorption unit (Scientific Instrument Services Inc., Ringoes, NJ) which introduced the aroma compounds directly into the injection port of a GC-MS (Hewlett-Packard G1800A GCD System, Palo Alto, CA). The experimental conditions for the GC analysis were as follows: column, J&W DB-Wax (30 m × 0.25 mm i.d., 0.25 μm film thickness); carrier gas, helium; flow, 1 ml/ min; split ratio, 1:10; injector temperature, 250 °C; oven program, 10 min at 40 °C, increased to 240 °C at 6 °C/ min, constant at 240 °C for 25 min. The mass selective detector operated in the electron ionization mode, scanning the m/z (mass/charge) ration between 20 and 450. Identification was carried out by probability-based matching with mass spectra in the G1033A NIST PBM library (Hewlett-Packard, Palo Alto, CA) and by matching with mass spectra obtained in the laboratory from reference compounds. Semi-quantitative data were obtained since data presented are based on areas of individual aroma compounds in total ion chromatograms relative to area of internal standard in the same chromatogram.

2.6. Statistical analysis

All sensory and instrumental data were subjected to statistical analysis using ANOVA (SAS version 8.00, www.sas.com) to determine the statistical effects of cultivar, field replicate and wound healing time for each storage duration. Differences were determined on significance level $P < 0.05$.

The variations in the sensory attributes, chemical components and aroma compounds were also determined by multivariate data analysis on mean data of the replicates using The Unscrambler statistical package (v7.5 CAMO A/S, Norway, www.camo.com). Principal component analysis (PCA) revealed the structure in the data by which the effect of design variables was

determined, and correlation between variables was established. Partial least squares regression was used to investigate relationships between sensory flavour (*Y*-variables) attributes and chemical data (*X*-variables) on the total data set from all storages. The predictions were determined by the correlation co-efficients (*r*) between measured and predicted variables. Regression co-efficients (*b*-co-efficients) for each of the chemical data (*X*-variables) were estimated by jack-knifing, and significances here of were determined. The *b*-co-efficients give the actual contribution of each chemical variable to the predictive model for the *Y*-variable. All the data were standardized, and the model evaluations were based on full leave-one-object-out cross-validation (Martens & Martens, 1986).

3. Results and discussions

3.1. Effects of cultivars, wound healing time and storage on quality

The effects of cultivars, wound healing time and storage on sensory attributes and chemical components were determined by analysis of variance. Cultivars had significant influence and contributed with the largest part of the variation in the chemical components in the raw potatoes (Table 1) and the sensory attributes (Table 2) and aroma components in the cooked potatoes. Also, storage had a significant effect on most of the variables. In contrast, duration of wound healing only had a significant effect on the intensity of surface hardness, yellowness and a few chemical components. The results are given below.

Analysis of variance gives the significant effects of factors on single quality attributes. In order to investigate the relationship between the large numbers of measured quality variables and the effect of design variables on these, a PCA on sensory, chemical and aroma components was performed. Due to no significant effect of field replicate, PCA was performed on means over field replicates.

3.2. Chemical variation of raw potatoes

The PCA plot of the chemical components in raw potatoes shows large variations in the content of free amino acids, caffeic acid, PPO, total-N, nitrate, and colour of blended potato pulp (delta-L, -a, -b) (Fig. 1). Variations were mainly cultivar dependent as the cultivars were positioned all over the plot and less influenced by wound healing time and storage duration as wound healing time and storage duration were grouped within each cultivar (Fig. 1, Table 1). In a PCA plot, the variables positioned nearby each other are highly positively correlated and variables positioned

Table 1
Chemical components in six potato cultivars before storage (storage 0) and significant effects of design variables on chemical composition

	Dry matter[a]	Starch[b]	N[b]	K[b]	Nitrate[b]	Caffeic acid (×10⁻³)[b]	PPO[c]	Chlorogenic acid (×10⁻³)[b]	Tyrosin[b]	Asparagine[b]	Aspargic acid[b]	Glutamine[b]	Glutamic acid[b]	Black spot index	Delta L
Marabel	170d	735a	13.0a	23.2a	0.116ab	15.5c	1.65bc	27.5b	0.70b	5.00ab	0.99cd	7.29a	2.45a	1.50c	2.34d
Berber	181c	767b	10.7b	20.8bc	0.067bc	11.6d	1.69bc	23.5bc	0.77ab	4.09b	0.90d	4.93bc	2.87b	7.50ab	3.47b
Arkula	189bc	770b	11.5ab	19.9c	0.119a	10.3d	3.11a	37.7a	0.80a	5.75ab	1.27ab	6.48ab	2.88b	11.3a	4.62a
Agria	198a	772b	10.9ab	22.5a	0.019c	24.7a	1.74b	36.0a	0.79ab	4.94ab	1.03cd	3.67c	2.28a	5.25bc	2.54dc
Folva	193ab	767b	9.80b	20.9bc	0.100ab	20.8b	1.81b	20.3c	0.56c	5.43ab	1.10bc	3.72c	2.31a	7.00ab	2.98c
Sava	192ab	763b	11.5ab	21.9ab	0.084ab	15.6c	1.22c	36.7a	0.85a	6.74a	1.36a	3.15c	2.52a	9.08ab	4.97a
Cultivar	***[d]	*	*	***	**	***	***	***	***	ns	***	**	**	*	***
WH[e]	ns	**	ns	ns	ns	ns	***	*	ns	ns	***	ns	ns	ns	Ns
Cultivar × WH	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	Ns

Different letters indicate significant differences on $P>0.05$.
[a] g/kg fresh weight.
[b] g/kg dry weight.
[c] μmol O_2 mg protein^{-1} min^{-1}.
[d] Significance levels (*** $P<0.001$, ** $P<0.01$, * $P<0.05$, ns = not significant).
[e] Wound healing.

Table 2
Sensory quality of six potato cultivars before storage (storage 0) evaluated on a 0–15 point scale and significant effects of design variables on sensory attributes

	Yellowness	Reflection	Surface hardness	Firmness	Mealiness	Adhesiveness	Moistness	Potato flavour	Off-flavour	Rancidness
Marabel	9.3b	0.6c	5.0c	4.6c	7.1d	8.6ab	6.7a	3.4d	7.0b	8.6a
Berber	6.1c	4.3a	7.9a	3.5d	9.7a	9.00a	4.5bc	4.6bc	5.4c	6.4b
Arkula	6.3c	2.0b	7.2ab	5.5bc	8.5b	8.2bc	3.8cd	4.0cd	8.0a	4.9c
Agria	11.0a	3.8a	6.6b	6.5a	7.8c	8.0bc	3.2d	6.1a	4.9c	3.8c
Folva	11.1a	1.3bc	5.4c	6.5a	6.3e	7.8c	4.8b	6.1a	4.5c	3.7c
Sava	10.8a	1.1c	7.9a	6.4ab	6.1e	6.9d	5.1b	5.0b	6.7b	4.1c
Cultivar	***[a]	***	***	***	***	***	***	***	***	***
WH[b]	**	ns	***	ns	ns	ns	ns	ns	ns	Ns
Cultivar × WH	ns	ns	Ns	ns	*	ns	ns	ns	ns	Ns

Different letters indicate significant differences on $P > 0.05$.

[a]Significance levels ($^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$, ns = not significant).
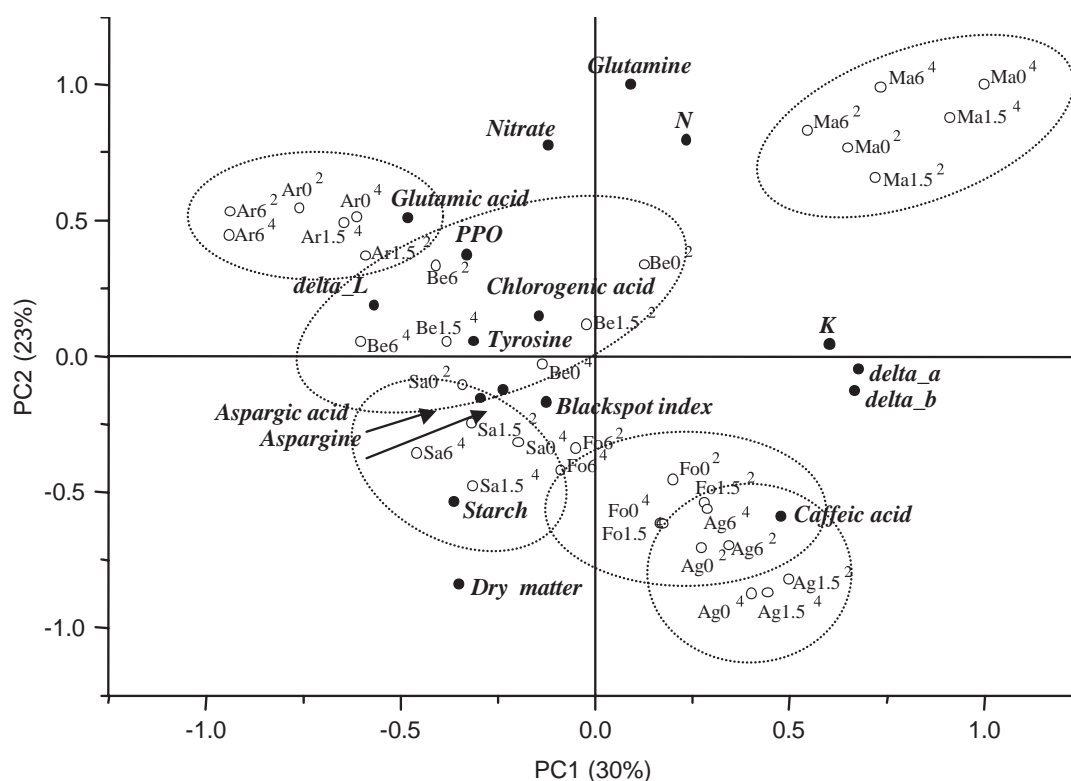
[b]Wound healing.

Fig. 1. Variation in 17 chemical/physical data in six raw potato cultivars wound healed for 2 or 4 weeks and stored for 0, 1½ and 6 months given by a PC1 versus PC2 in a PCA bi-plot. *Abbreviations*: Be1.5²: Be = Berber, 1.5 = storage, ² = wound healing time. M in Be6⁴M and Sa6⁴M indicates an extra mechanical stress exposure.

directly oppositely are negatively correlated. Therefore, the enzymatic discolouration potential (delta-L) correlated with the content of the amino acids tyrosine, glutamic acid, asparagine and aspartic acid, chlorogenic acid and the activity of PPO, and was inversely correlated to an increase in a and b colour values and the content of potassium and caffeic acid. The high correlation between enzymatic discolouration and the

activity of PPO and its substrates tyrosine and chlorogenic acid is well known (Friedman, 1997). However, the correlation to the content of asparagine and aspartic acid is new, and might be due to secondary effects. Although caffeic acid is known to be a substrate for PPO, our results indicate a negative correlation between caffeic acid and enzymatic discolouration, due to the negative correlation between caffeic acid and the
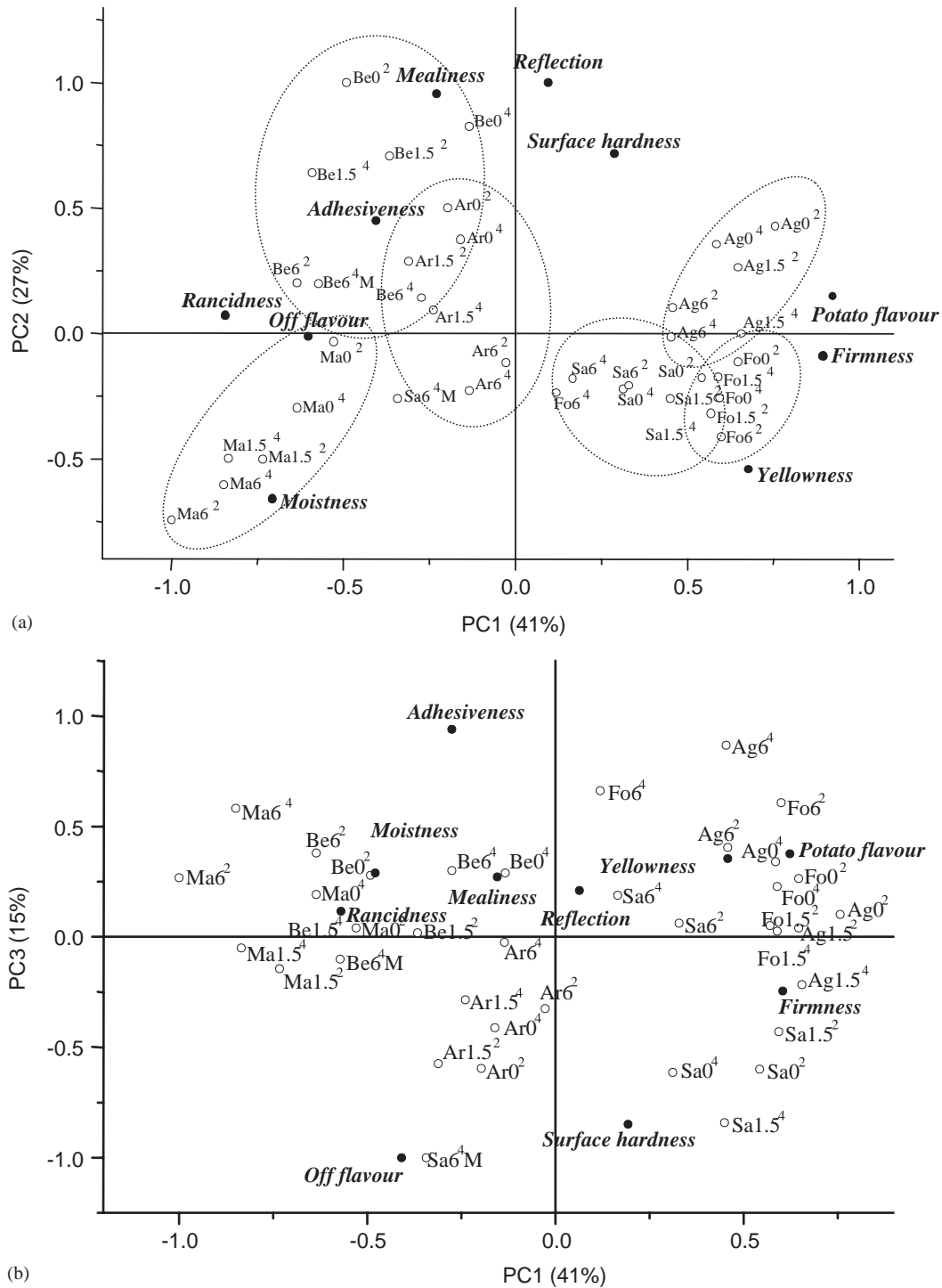
Fig. 2. Variation in 10 sensory attributes measured in six cooked potato cultivars wound healed for 2 or 4 weeks and stored for 0, $1\frac{1}{2}$ and 6 months given by a PC1 versus PC2 (a) and PC1 versus PC3 (b) in a PCA bi-plot. *Abbreviation*s: Be1.5^2: Be = Berber, 1.5 = storage, ^{2} = wound healing time. M in Be6^{4}M and Sa6^{4}M indicates an extra mechanical stress exposure.

other PPO substrates tyrosin and chlorogenic acid. In agreement with our findings, McNabnay, Dean, Bajema, and Hyde (1999) reported a reduction in discolouration of tubers with an increase in potassium content, due to a decrease in tyrosine content rather than to a decrease in PPO activity. Nitrate, total-N and glutamine

content were inversely correlated with content of dry matter and caffeic acid. The inverse correlation between dry matter content and the content of total-N and glutamine (Fig. 1, PC2) is well established and has been reviewed by Perrenoud (1983). Arkula and Sava had high contents of chlorogenic acid, tyrosine, asparagine,
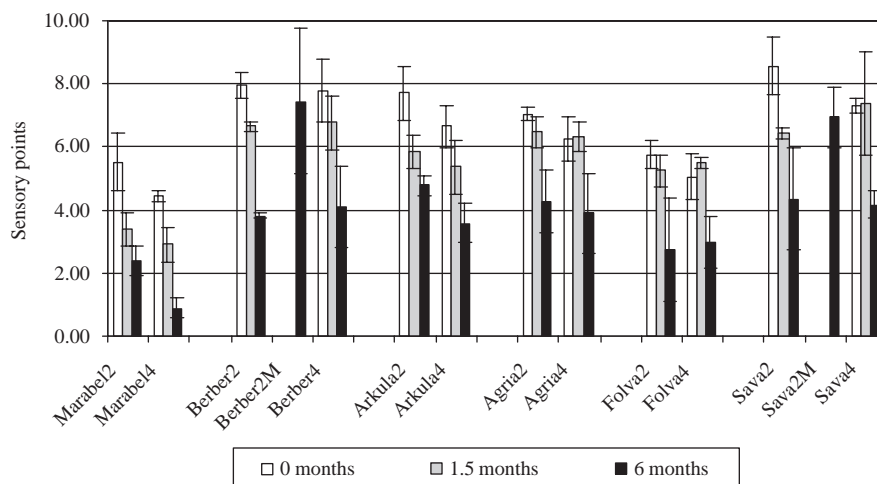
Fig. 3. Sensory surface hardness in six cooked potato cultivars wound healed for 2 or 4 weeks and stored for 0, 1½ and 6 months evaluated on a sensory scale from 0 to 15. 2 and 4 indicate wound healing time. M in Berber2M and Sava2M indicates an extra mechanical stress exposure.

aspartic acid and high levels of enzymatic discolouration (Fig. 1, Table 1). Agria had relatively low content of nitrate and high caffeic acid content. Marabel was characterized by a relatively higher content of nitrate, total N, glutamine, K and low dry matter content. Some of these cultivar-specific variations can be explained by earliness-related differences in the physiological maturity of their tubers at harvest. The prolonged wound healing treatment significantly decreased the activity of the PPO (data not shown). Furthermore, the enzymatic discolouration potential decreased with increasing wound healing time as reported by Dean, Jackowiak, Nagle, Pavek, and Corsini (1993); however, this decrease was not statistically significant.

3.3. Sensory quality of cooked pre-peeled potatoes

Sensory mean data for the six cultivars before storage are given in Table 2. Significant differences between cultivars exist for each sensory attribute. A PCA of the sensory attributes from the full set of samples showed that the cultivars (Fig. 2a, PC1) and storage duration (Fig. 2a, PC2) described a major part of the variation in the sensory attributes (68% explained variance), which consisted of a flavour/taste, a colour and a texture variation. An inverse correlation between negative taste and flavour attributes (off-flavour and rancidness) and potato flavour was found between cultivars. From Table 2 it is obvious that the cultivars Agria, Folva and Sava had high intensity of potato flavour, yellowness and firmness and low intensity of rancidness and off-flavour, which is confirmed in Fig. 2a (PC1). Thus these cultivars had a very good eating quality. However, Sava had high intensity in surface hardening and was therefore less appropriate for a pre-peeled potato product. Sava and Berber had the highest intensity in surface hardening

(Table 2). An increased mechanical stress induced to Berber (Be6⁴M) and Sava (Sa6⁴M) after peeling increased the intensity in rancidness, off-flavour and surface hardness (Fig. 2a, PC1). This result indicates that mechanical stress deteriorates sensory quality. The cultivar Marabel had the highest intensity of off-flavour, rancidness and moistness and lowest intensity in potato flavour and firmness (Table 2, Fig. 2a). Marabel therefore seemed to be a less appropriate cultivar for this type of convenience product. In Fig. 2b (PC1, PC3), the three flavour attributes potato flavour, rancidness and off-flavour can be separated. Here it is obvious that off-flavour varied with storage in contrast to potato flavour, which remained less affected by storage (Fig. 2b). Off-flavour decreased with an increase in storage and increased with mechanical stress (Fig. 2b, PC3). A variation in sensory mealiness, reflection from surface and moistness was mainly caused by storage (Fig. 2a, PC2). Mealiness and reflection from surface decreased with increased long-term storage as moistness increased.

A single plot of surface hardness illustrates that surface hardness is affected by cultivar, storage and duration of wound healing (Fig. 3). The significantly highest surface hardness was observed in Sava and Berber and the lowest in Agria. Prolonging the wound healing time from 2 to 4 weeks before cold storage of tubers reduced the surface hardness in pre-peeled potatoes slightly. The undesirable surface hardness was most pronounced right after harvest and was highest in potatoes subjected to increased mechanical stress (Berber 2M, Sava 2M), which is in accordance with observations in the industry (private communication). As stated previously, the formation of a surface hardening is speculated to be a part of the wound healing process as peeled stress-induced potatoes may perform a defence towards evaporation and microbial
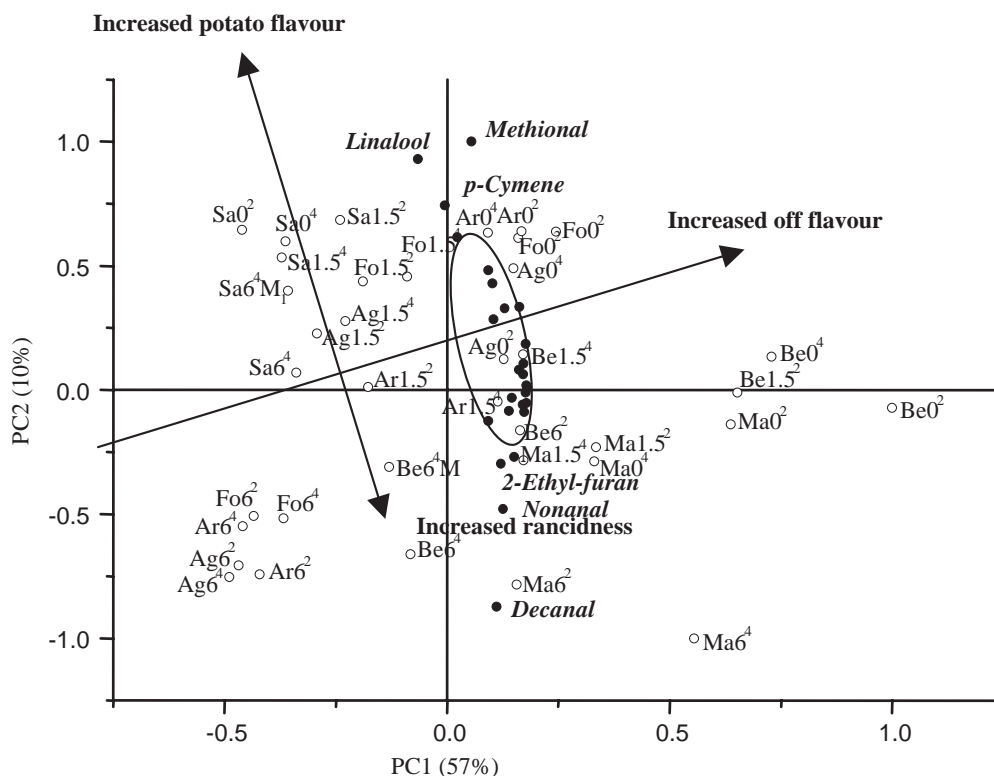
Fig. 4. Variation in 26 aroma components in six cooked potato cultivars wound healed for 2 or 4 weeks and stored for 0, $1\frac{1}{2}$ and 6 months given by a PC1 versus PC2 in a PCA bi-plot. *Abbreviation*s: Be1[2]: Be = Berber, 1.5 = storage, [2] = wound healing time. M in Be6[4]M and Sa6[4]M indicates an extra mechanical stress exposure. The circle represents a large group of highly correlated aroma components: pentanal, hexanal, heptanal, (E)-2-hexenal, furan-2-pentyl, 1-pentanol, octanal, (E)-2-heptenal, 1-Hexanol, E-2-octenal, 1-octen-3-ol, 2,4-heptadienal, (E,E)-2,4-heptadienal, E-2-nonenal, dimethyl sulphoxid, (E,E)-2,4-octadienal, 2,4-nonadienal, (E,E)-2,4-decadienal, butyl butyrat, phenol.

growth during the 5–7 days of shelf-life (Kaack et al., 2002b). This may also explain the significant increase in surface hardening in potatoes exposed to extra mechanical stress. In accordance with these observations, the surface hardness of pre-peeled potatoes seems to be correlated to tubers having a high metabolic activity, like immature or mechanically stressed tubers. The high respiration rate in tubers during wound healing at 14 °C will secure the metabolism of excessive amounts of low molecular substances like mono saccharides and amino acids, leading to physiological mature tubers with low metabolic activity and less surface hardening.

3.4. Aroma profile in cooked pre-peeled potatoes

A PCA of the aroma components indicates that the variation in most of the aroma components was mainly caused by effects of cultivar and storage (Fig. 4, PC1 and PC2). A comparison of the effects provoking the variation in the sensory quality (Fig. 2a and b) and the variation in aroma composition (Fig. 4) results in an "off-flavour" variation around PC1 and a "potato flavour/rancidness" variation around PC2. The variation in the aroma components was mostly found in PC2

in Fig. 4. The sensory off-flavour variation (Fig. 2a and b) was not represented by a distinct variation in the measured aroma components (Fig. 4, PC1). A large group of highly correlated aroma components, thus expressing the same type of information, were found around origin in Fig. 4. These aroma components did not contribute to a differentiation in aroma profiles between the potato samples with high variation in off-flavour. In contrast, the aroma components methional, linalool, *p*-cymene, nonanal and decanal characterized aroma differences between potato cultivars and storage. High intensity of methional, linalool and *p*-cymene and low intensity of nonanal and decanal was found in nonstored potatoes Sava, Folva and Agria with high levels of sensory potato flavour and low scores for rancidness (Fig. 2a). In contrast, high intensity of nonanal and decanal was found in the cultivars Marabel and Berber with high intensity of rancidness and low intensity in potato flavour. The high similarity in the position of the cultivars in the PCA plots of sensory data and the aroma data indicates that the measured aroma components determined the potato flavour versus rancidness variation between the cultivars and storages. Methional, nonanal and decanal were identified in

Table 3
Overview of chemical variables with significant influence on flavour and taste attributes in pre-peed cooked potatoes determined by PLS regression co-efficients (+ indicates a significant positive correlation and − a significant negative correlation between each chemical data and the quality attribute)

	Potato flavour ($r = 0.88$)[a]	Rancidness ($r = 0.83$)	Off-flavour ($r = 0.87$)
Dry matter	+ ***[b]	−***	−**
Chlorogenic acid	−*	ns	+***
Caffeic acid	+**	ns	−*
Tyrosin	−*	ns	+*
Total N	−***	+***	+***
Nitrate	−**		+***
Aspargine	ns	ns	ns
Aspargic acid	ns	ns	ns
Glutamine	−***	+***	+***
Glutamic acid	−**		+***
2-Ethyl-furan	−***	+**	+*
Pentanal	ns	+**	ns
Hexanal	ns	+***	ns
Heptanal	ns	ns	ns
(E)-2-Hexenal	−*	+**	ns
2-Pentyl-furan	ns	ns	+*
1-Pentanol	ns	+*	ns
p-Cymene	ns	−*	+*
Octanal	ns	ns	ns
(E)-2-Heptenal	ns	ns	ns
1-Hexanol	ns	ns	ns
Nonanal	ns	+*	−*
E-2-Octenal	ns	+***	ns
Methional	+*	−**	ns
1-Octen-3-ol	ns	+*	ns
2,4-heptadienal	−**	+*	+*
(E,E)-2,4-Heptadienal	−**	+*	+**
Decanal	ns	+***	ns
(E)-2-Nonenal	+**	ns	ns
Linalool	+**	−**	ns
Dimethyl sulfoxid	−*	+*	ns
2,4-Nonadienal	ns	+**	ns
(E,Z)-2,4-Decadienal	−*	+**	ns
(E,E)-2,4-Decadienal	ns	ns	ns
Butyl byturate	ns	ns	ns
Phenol	ns	ns	ns

[a]Correlation co-efficient between sensory attribute and all chemical components.
[b]Significance levels (***$P < 0.001$, **$P < 0.01$, *$P < 0.05$; ns: not significant).

potatoes in earlier studies, which also included GC-olfactometry (Petersen, Poll, & Larsen, 1998, 1999). Methional is formed during boiling of potatoes and has a distinct boiled potato odour. The concentration of nonanal was shown to increase during storage of boiled potatoes and its odour quality was described as 'rancid'. Decanal was also found in boiled potatoes, and it was contributing with a 'fatty' odour. In the studies mentioned, linalool and p-cymene were not identified, but since their odour qualities are described as 'floral' and 'reminiscent of carrot' (Burdock, 1994) it seems

likely that the correlations with potato flavour are causal. The aroma profile of Sava and Berber exposed to an extra mechanical stress after peeling was very similar to the aroma profile of nonstressed Sava and Berber. Thus the sensory differences in off-flavour found for the stressed versus nonstressed potatoes (Sava and Berber, Fig. 2a and b) were not reflected by the aroma profile. This result confirmed the lack of correlation between aroma components and off-flavour.

3.5. Correlations between sensory quality and chemical compounds

As this study shows, significant effects of raw material quality on chemical constituents related to flavour and taste attributes of pre-peeled potatoes, correlation between the quality attributes as potato flavour, off-flavour and rancidness and the relevant chemical constituents was determined by PLS regression. Table 3 gives the negative or positive correlation between the chemical variables and the quality attributes. The overall correlation co-efficients between potato flavour, rancidness and off-flavour, and the measured chemical compounds were $r = 0.88$, 0.83 and 0.87, respectively.

The content of dry matter, chlorogenic-, caffeic- and glutamic acid, glutamine, tyrosin, nitrate and total N had a significant effect on potato flavour and off-flavour, but affected the sensory attributes inversely. With respect to aroma compounds a significant effect of 8, 16 and 6 aroma compounds were found for potato flavour, rancidness and off-flavour, respectively. Thus, in contrast to potato flavour and off-flavour, rancidness was significantly affected by many aroma compounds and less affected by nonvolatile compounds. Table 3 shows that many aroma compounds affected potato flavour and rancidness inversely, which is in accordance with observations in Fig. 1. A high content of dry matter, caffeic acid and the aroma components heptanal, methional and linalool was positively correlated to potato flavour and negatively correlated to rancidness. As described previously, methional was identified as a boiled potato odour and linalool as a floral odour (Petersen et al., 1998, 1999). Even though potato flavour is an attribute predominately determined by aroma compounds, potato flavour is also dictated by certain nonvolatile compounds, such as amino acids and sugars, which can serve as precursors for the formation of thermally produced volatiles, as well as certain nucleotides, which can act as flavour potentiators (Maga, 1994). A high content of total N, nitrate, glutamine, glutamic acid, 2-ethyl-furan, (E)-2-hexenal, 2,4-heptadienal, (E,E)-2,4-heptadienal, dimethyl sulphoxid and (E,Z)-2,4-decadienal was negatively correlated to potato flavour and positively to rancidness. Some of these aroma components mentioned are reaction products of

lipid oxidation, and the aldehydes have previously been shown to be associated with another type of off-flavour in boiled potatoes arising when boiled potatoes are cold-stored (Petersen et al., 1999). As noticed in Fig. 2b (PC3), off-flavour was not correlated with potato flavour and rancidity, thus expressing another type of flavour/taste dimension in the potatoes. This may be explained by the fact that off-flavour was pronouncedly dictated by nonvolatile compounds and to a lesser extent affected by aroma compound (Fig. 4, Table 3). This is in accordance with previous results, stating that off-flavour/off-taste was defined as the bitter and scratchy taste probably combined with some degree of burning, which was related to nonvolatile compounds as phenolics and glycoalkaloids (Maga, 1994).

4. Conclusion

This study showed that raw material quality and the physiological maturity of the potatoes is a great challenge for the industry in order to optimize the sensory quality and to decrease the presence of quality defects such as surface hardening. The results indicate that some potato cultivars are not suitable for a convenience product as pre-peeled potatoes, either due to surface hardening or negative flavour and taste perception. Choice of cultivar is therefore a very important factor in product development. With respect to raw material quality, an increased wound healing time decreased the problem of surface hardening slightly. Results obtained show that full maturity of the tubers at harvest and a prolonged wound healing are important in order to minimize surface hardening problems in pre-peeled potatoes. Mechanical stress induced to the peeled potatoes also seems to be very important for surface hardening, which already is known to be the major cause for quality deterioration in pre-peeled potatoes in the industry. In this study, it was possible to identify some of the chemical components with high relevance for discolouration susceptibility and positive and negative flavour and taste attributes. These results contribute to the understanding of the reason for the quality deterioration and improvement of the production of pre-peeled potatoes.

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